BELLCOMM, INC.
1100 SEVENTEENTH STREET, N.W. WASHINGTON, D.C. 20036

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- A Parametric Study on the Use of Diluent Gases as a Means of Extinguishing Spacecraft Fires in Flight

TM-67-2032-1

DATE-April 17, 1967

FILING CASE NO(S)-330

AUTHOR(S)-L. G. Miller

FILING SUBJECT(S)-
(ASSIGNED BY AUTHOR(S)- Spacecraft Depressurization
Diluent Gases
Fire Extinguishing

ABSTRACT

Spacecraft cabin depressurization and concurrent repressurization with a diluent gas is examined as a strategy for dealing with spacecraft fires in flight. The basic philosophy is to quickly reduce the partial pressure of oxygen below the level which would support combustion while, at the same time, maintaining total cabin pressure at a level which would prevent detrimental physiological effects. This design approach attempts to determine (1) what are the relative advantages to using either helium or nitrogen as a diluent gas, (2) what type of hardware configuration is indicated, and (3) how should the system be employed. Procedural requirements are developed in the light of proposed system capabilities.

It is recommended that experiments be performed to determine whether rapid reduction of oxygen partial pressure (i.e. 5-15 seconds) combined with maintaining a total cabin pressure of 3 psia, by means of a diluent gas, is effective as a means of extinguishing a fire. If warranted, it is further recommended that a study be initiated to select the best diluent gas and hardware combination, with special attention given to a number of questions which were posed on gas dynamics and pressure effects.

Though not directly related to the diluent gas study, a figure is included which shows the relation between orifice area and depressurization time in a vacuum for the Block II CM.

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[2]Proposed NASA-TN (presently undergoing technical review) on the subject of Fire Extinguishment in an Oxygen-rich Hypobaric Environment, by J. H. Kimzey, MSC/ES4; see also NASA film entitled "Flame Propagation," MSC film roll CL-67-354.

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With this as background, the writer conceived the idea of partially depressurizing the spacecraft cabin upon discovering the presence of a fire and concurrently repressurizing the cabin with a diluent gas. While this would create convection currents, the basic strategy would be to quickly reduce the partial pressure of oxygen below the level which would support combustion while, at the same time, maintaining total cabin pressure at a level which would prevent detrimental physiological effects. This memorandum reports the results of this study and suggests certain design considerations for a fire extinguishing system which could be used in flight. It is, however, a design approach only since the feasibility of implementing the concept is a subject which is not within the scope of this work. The study does yield procedural requirements in the light of proposed system capabilities.

ASSUMPTIONS

The computer program developed for this study is an extension of the DEPRES Program reported in the reference of Footnote 1. As such, it retains all of the basic capabilities and assumptions of the DEPRES Program. An option which allows repressurization with a diluent gas has been added. Dalton's Law is used to develop partial pressures, and Gibb's Law is used to calculate the physical properties of the mixture of two gases. More specifically:

1. Depressurization and repressurization take place at the same time, and it is assumed that this combination of activities results in a process which can roughly be described as isothermal. That is, the large heat capacity of the cabin is assumed to exert the major influence on cabin temperature. This assumption is further enhanced by the short period of time during which the fire extinguishing system operates.

2. It is assumed that perfect and instantaneous mixing of the two gases occurs.

3. It is assumed that the spacecraft is in flight and the cabin is pressurized to 5 psia with pure oxygen.

4. Astronauts could be either in or out of their suits. If the astronauts were in "shirt sleeves," it must necessarily be assumed that the crew has individual, fire resistant emergency oxygen supplies and masks similar, perhaps, to those used in high performance aircraft. It is understood that a number of such devices is presently being evaluated.

5. It is assumed that the spacecraft contains adequate provisions for fire detection.

SEQUENCE OF EVENTS

On discovering the presence of a fire in the spacecraft cabin, the following actions must take place:

1. Turn off cabin oxygen supply and circulating fans. (It may also be worthwhile to investigate the merit of turning off spacecraft power at this time.)

2. Vent spacecraft. (Astronauts would have to activate their emergency oxygen supplies at this point if they were out of their suits.)

3. Activate purge of diluent gas.

4. Close cabin vent and turn off purge when partial pressure of oxygen drops sufficiently (probably determined by requiring operation of the purge for a specified period of time).

5. Take necessary action to prevent reoccurrence of fire.

It follows that these events must take place within certain physiological boundary conditions in order to permit the astronauts to continue functioning. The following guidelines[3] have been used:

1. Total pressure not less than 1.6 psia 1.7 seconds after having initiated cabin vent.

2. Partial pressure of oxygen less than or at most equal to 40 mmHg (0.8 psi) within 10 seconds after initiation of cabin vent[4].

3. Total pressure not less than 1.6 psia for more than 3 seconds.

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[3]Physiological Constraints to Emergency Cabin Depressurization - Case 330 (Draft) by T. A. Bottomley, Jr.

[4]Information available from preliminary MSC tests indicates that, in general, combustion will not continue in a 3 psia atmosphere (in orbit) if the partial pressure of oxygen is less than 40 mmHg. (Staklis, A. A., Fire Control for Spacecraft with 5 psia Oxygen Atmosphere, Proposed NASA Tn 5-136, October 14, 1966.)

4. Total pressure not less than 2.7 psia for more than 15 seconds.

5. Total pressure greater than or equal to 3.0 psia after 2 minutes.

Existing physiological data indicates that the astronauts can continue to function if the above conditions are maintained.

STUDY PARAMETERS

Interest has been expressed in the use of either helium or nitrogen as a diluent gas, hence the computer program was written to permit easy substitution of the appropriate gas characteristics. The diluent gas reservoir size and flow rate were sized to allow attainment of a steady state flow condition. Preliminary work established the threshold cabin pressure value for starting the flow of diluent gas. This was then sized to ensure that the physiological boundary conditions were not exceeded. A lower bound on cabin pressure was selected as the point at which the maximum flow rate of diluent gas would become available. Between the threshold pressure and this latter point, diluent gas flow rate varied linearly with pressure.

For a given gas, the area of the emergency cabin vent orifice or dump valve (hereafter referred to as the orifice area) was the primary study variable. Also examined was the effect of varying the time of initiation of diluent gas flow.

RESULTS

The results of this study are summarized in four figures. The first contains a family of curves showing the decay of partial pressure of oxygen versus time for a number of different orifice total areas[5]. As indicated, the diluent gas is helium. The shaded portion shows the pressure-time combinations which are considered to be desirable. That is to say, an oxygen partial pressure of less than .8 psi should not permit continuation of combustion, and this level should be reached within no more than ten seconds. The second figure shows a similar family of curves using nitrogen as a diluent gas.

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[5] This is not to be confused with effective area which is defined as the total or geometric area multiplied by the orifice coefficient.

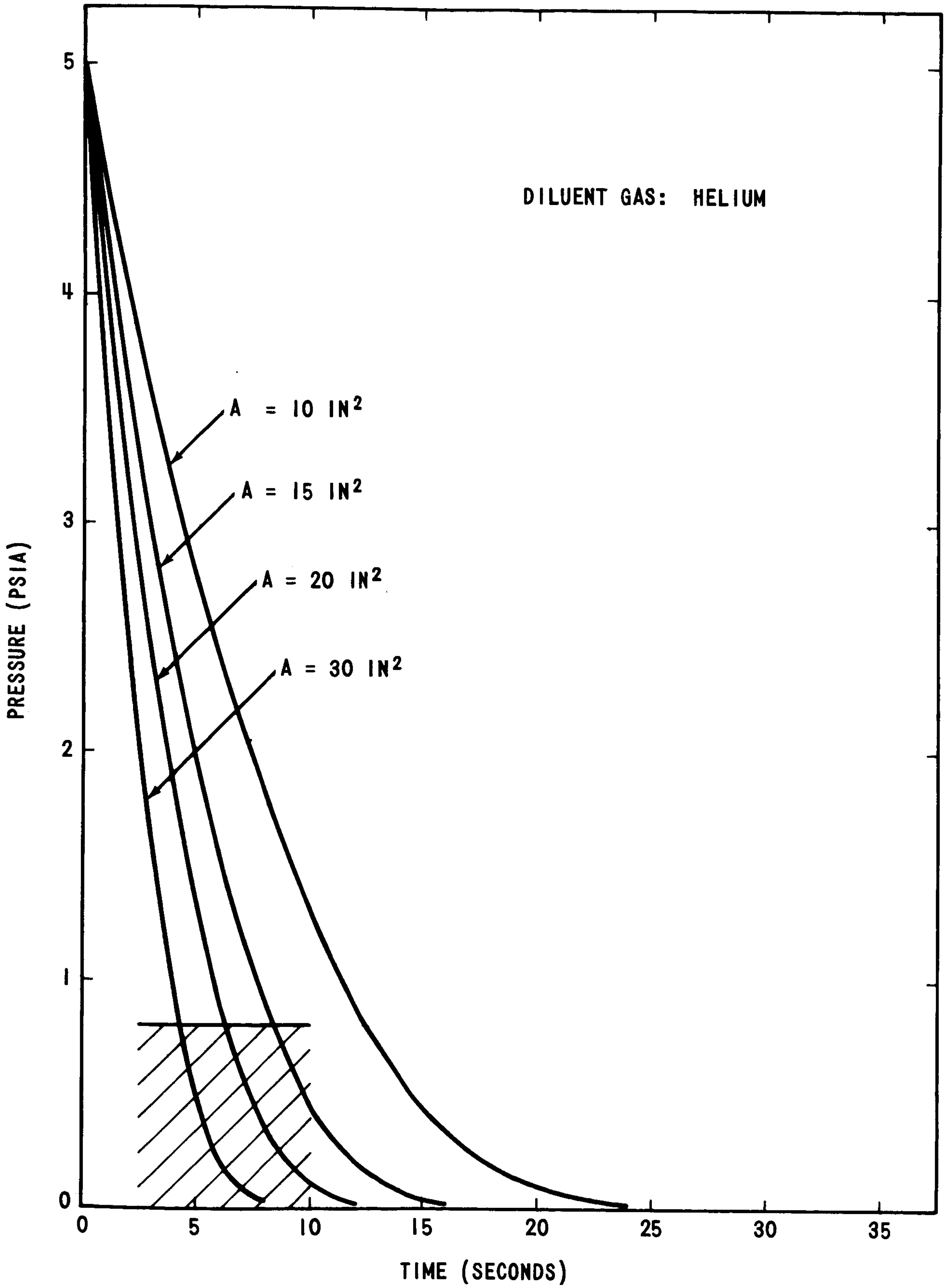

FIGURE 1 - PARTIAL PRESSURE OF OXYGEN VS. TIME FOR DIFFERENT ORIFICE AREAS

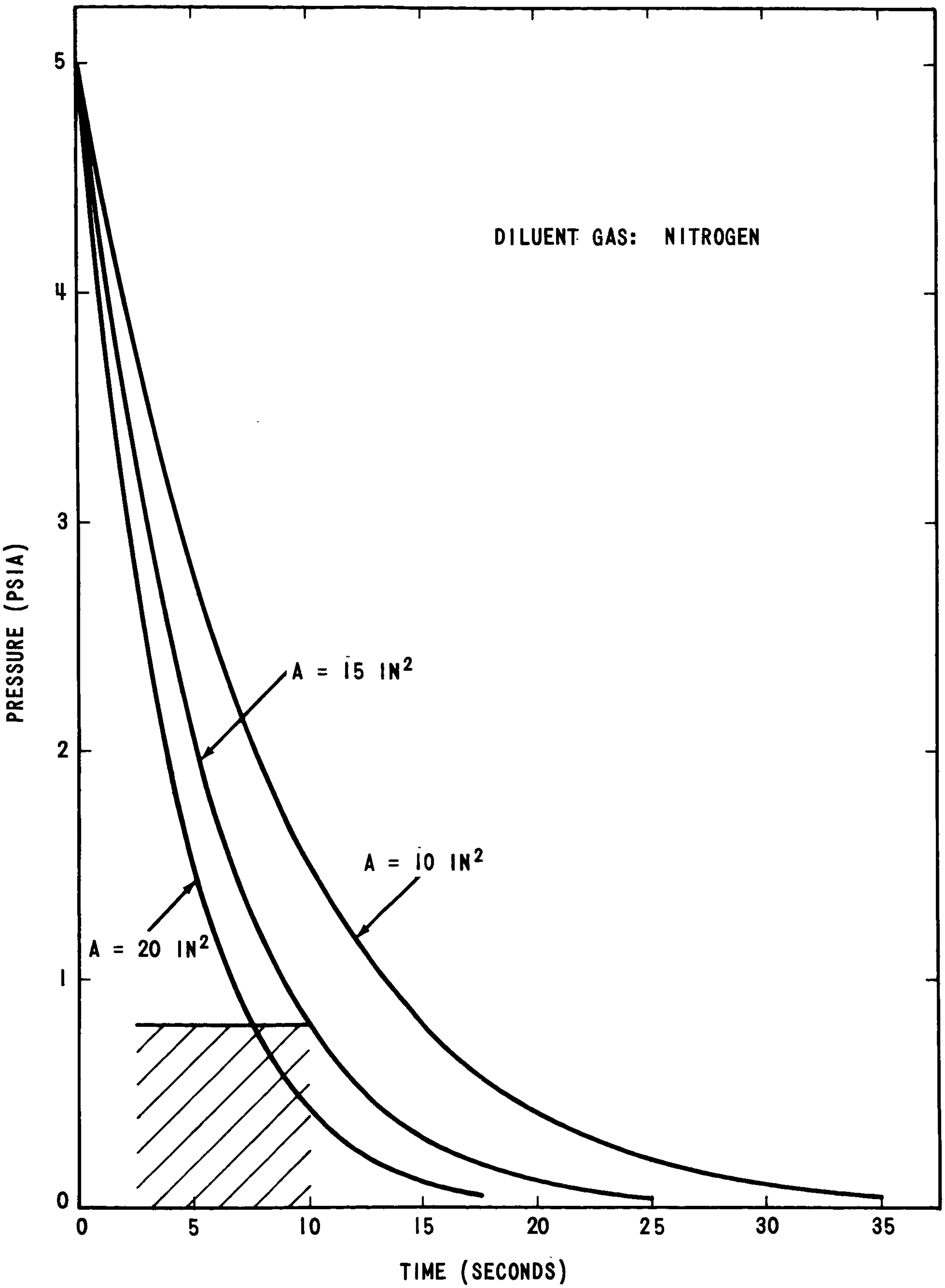

FIGURE 2 - PARTIAL PRESSURE OF OXYGEN VS. TIME FOR DIFFERENT ORIFICE AREAS

As was mentioned above, the first two figures were obtained assuming that cabin venting began at time equals zero and that flow of the diluent gas was controlled by a regulator which opened, linearly, from zero to full flow between preset cabin pressure limits. An ancillary study looked at the benefits to be gained by delaying the start of diluent gas flow for a specified period of time. While this strategy did result, momentarily, in a lower total cabin pressure, it is interesting to note that it has a negligible effect on the rate at which the partial pressure of oxygen decays. Therefore, there is nothing to be gained by employing this strategy, and efforts were subsequently aimed at obtaining the desired partial pressure of oxygen while maintaining the cabin pressure at an acceptable level.

Figure 3 plots total cabin pressure versus time for a typical example from each of the first two figures. The shaded area represents the physiological boundary which must be avoided. As is obvious, the model behaved quite decently. The fact that the curves level off indicates that a pseudo steady state condition has been achieved. That is, total cabin pressure does not decrease, but the partial pressure of oxygen continues to drop until it reaches zero.

For a given orifice area, the "steady state" total cabin pressure is a function of the maximum mass flow rate of diluent gas and the pressure levels at which the diluent gas regulator opens and closes. For the values selected, (i.e. diluent gas flow increases from zero to full flow between total cabin pressures of 3.20 and 2.90 psia), Figure 4 approximates the maximum flow rate of diluent gas required to maintain total cabin pressure at 3 psia for a given orifice area. No attempt was made to optimize these curves.

Though not directly related to the use of a diluent gas, Figure 5 has been included because of the general interest in the relation between orifice area and depressurization time. The curve shows, for an initial cabin pressure of 5 psia (100% oxygen), the time required to depressurize to 1.0 and 0.1 psia as a function of orifice total area. The Block II CM volume was used. An isothermal process was assumed with a cabin temperature of 75°F.

DISCUSSION

The results of this study point towards the answers to three basic questions. These are: (1) What are the relative advantages to using either helium or nitrogen as a diluent gas?

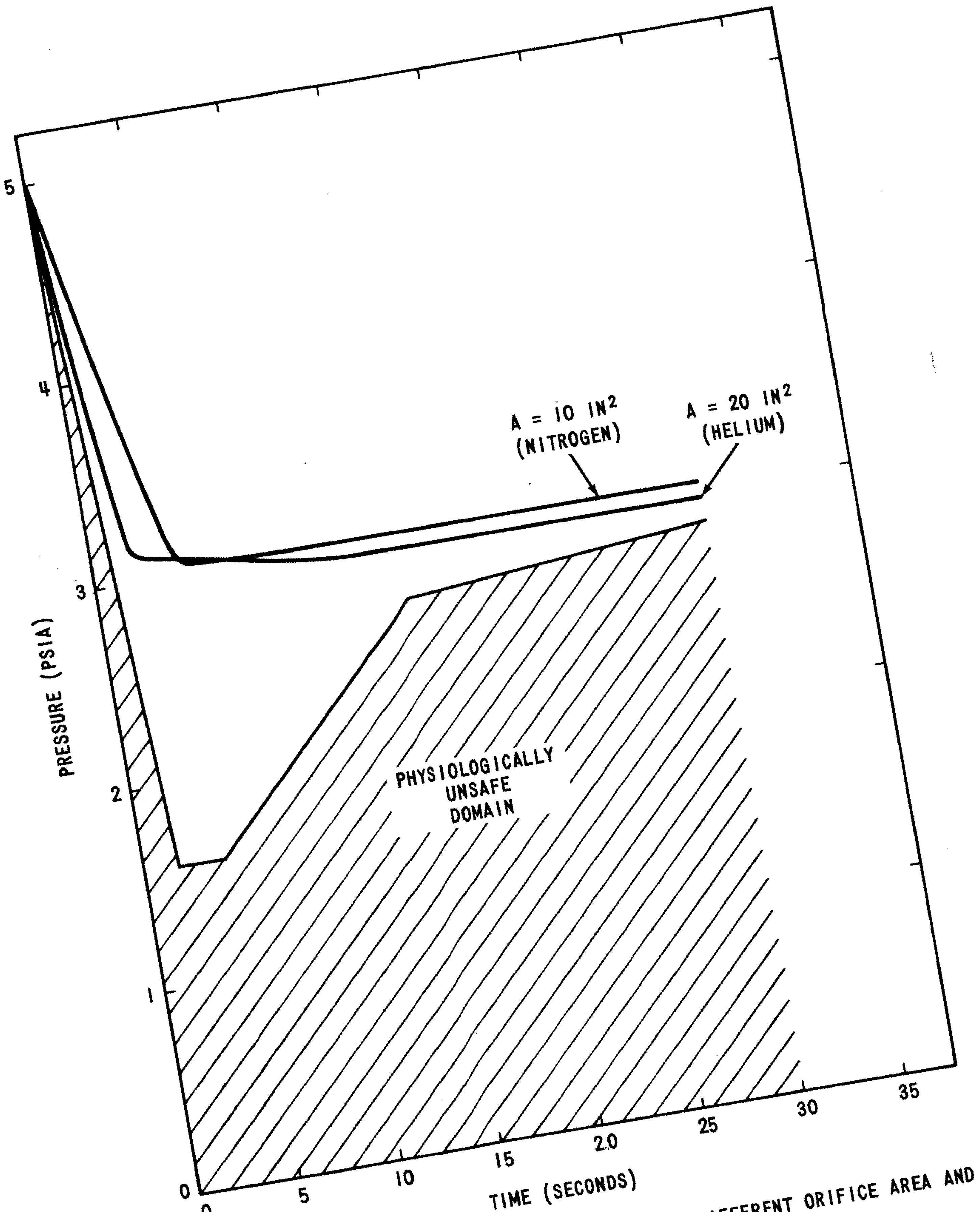

FIGURE 3 - TOTAL CABIN PRESSURE VS. TIME FOR DIFFERENT ORIFICE AREA AND DILUENT GAS COMBINATIONS

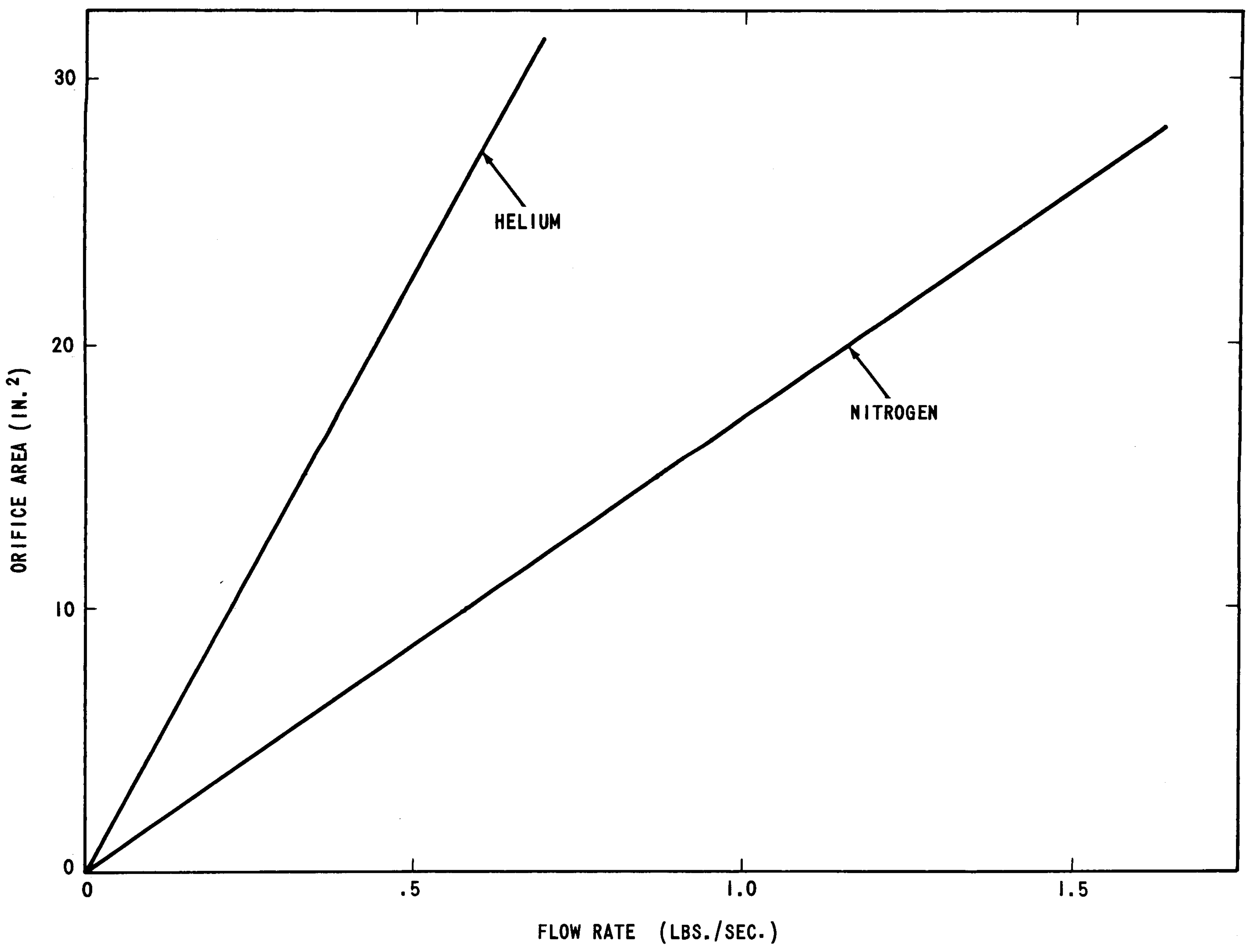

FIGURE 4 - MAXIMUM DILUENT GAS FLOW RATE REQUIRED TO MAINTAIN CABIN PRESSURE AT 3 PSIA

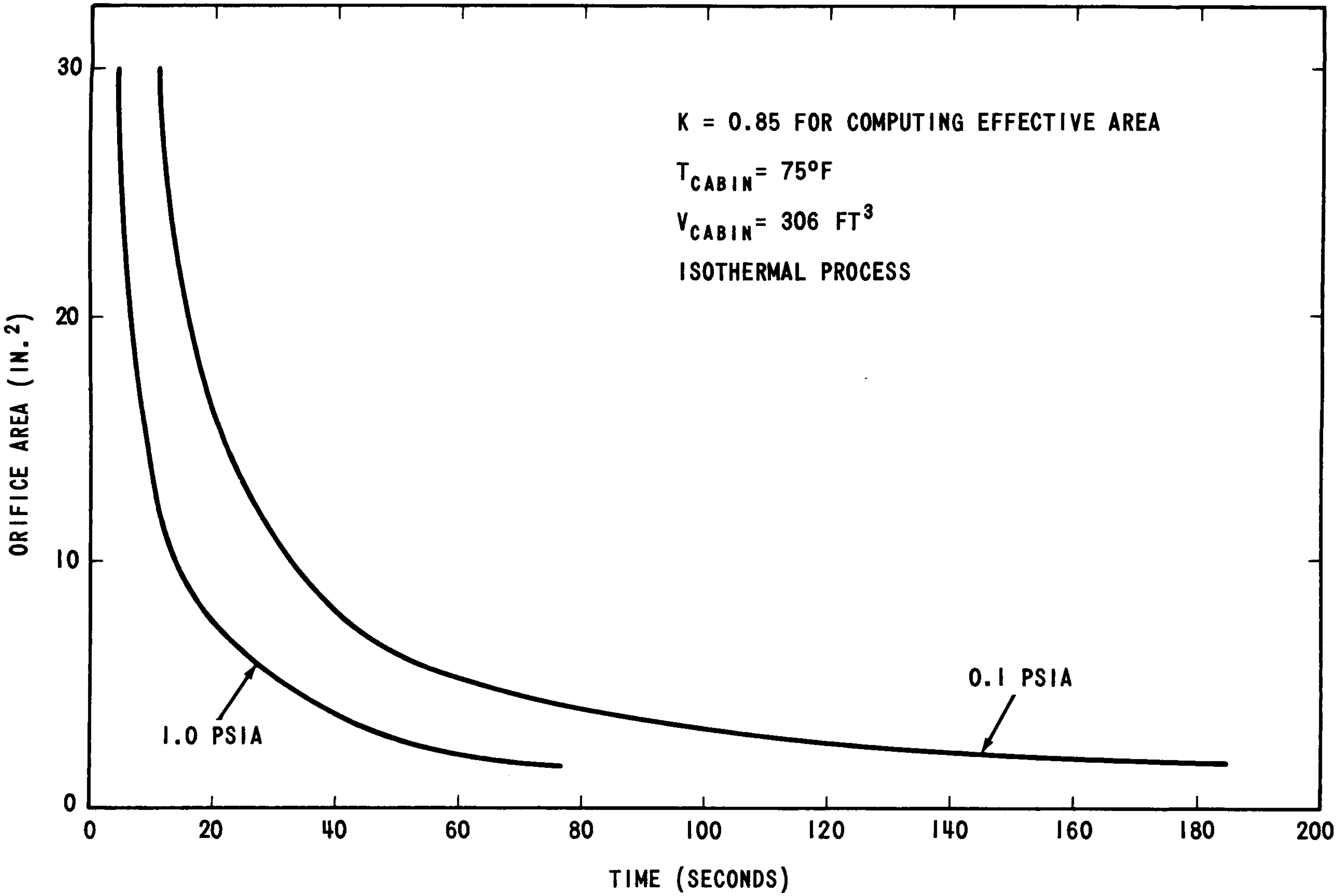

FIGURE 5 - TIME REQUIRED TO DEPRESSURIZE BK II CM CABIN FROM 5.0 PSIA TO EITHER 1.0 OR 0.1 PSIA AS A FUNCTION OF TOTAL AREA OF THE ORIFICE

(2) What type of hardware configuration is indicated? (3) How should the system be employed? To properly answer these questions, one should first examine the "nominal" case, and then look at the posture resulting from the occurrence of some gross secondary failures. In general, though, this memorandum follows the ASPO attitude that double failures will not be considered.

In the nominal case, a fire occurs, is quickly recognized, and the crew proceeds to carry out a number of pre-rehearsed actions. It is assumed that all equipment associated with the fire extinguishing system functions properly. Of primary importance is the rapidity with which the pre-rehearsed actions are initiated.

Reference to Figures 1 and 2 shows that it takes a longer time to reach a given partial pressure of oxygen when nitrogen is used as the diluent gas. Figure 4 indicates that the required mass flow rate of nitrogen is two or three times as great as helium for a given orifice area. Thus, considering only these gross factors, one might conclude that helium is the better choice as a diluent gas. But, unfortunately, the answer is not that simple. The selection of a diluent gas must also consider physiological problems such as decompression sickness and voice distortion which might arise if the diluent gas were subsequently to contaminate the suit loop or otherwise be inhaled. The heat-pulse problem, which deals with the rate of pressure and temperature rise in the cabin, must be analyzed for the nominal case and for the limiting case in which one is unable to relieve cabin pressure quickly. In addition, there will have to be an analysis of the dynamics of the high mass flows in order to ensure that the crew would not be injured by direct impingement or flying objects. However, physiological factors notwithstanding, it would appear that engineeering considerations will have to play a major role in the selection of a diluent gas. For the nominal case, reliability, weight, and hardware availability will no doubt be the major factors.

Turning to the hardware, the model postulates the need for a diluent-gas reservoir of some type. The size and construction, of course, are a function of the diluent gas, orifice area, and the number of operating cycles to be made available. To enhance the assumption of perfect mixing and provide for the comparatively large flow rates involved, it is proposed that the gas enter the cabin through a perforated torus located either above or below the crew couches. Reliability of the system might well be enhanced by providing, if the weight penalty is acceptable, two separate and redundant supply systems and diluent-gas regulators for the torus. The regulators, as previously mentioned, should permit increasing flow of the diluent gas between preset cabin pressure limits. Though not necessarily optimal, the limits used in the model are certainly capable of providing satisfactory performance.

It would also be advantageous to have a single control which enables the fire extinguishing system and opens the emergency dump valve, but this is not a mandatory requirement. Adequate training in the capabilities and operation of the system could do much to offset the inconvenience of requiring a number of separate actions to initiate the fire extinguishing cycle.

Figures 1 and 2 illustrate the type of decision involved in selecting an area for the emergency dump valve. As fire grows in intensity, greater amounts of fuel may become available, thus contributing to further malfunctions. The rate at which the oxygen partial pressure is reduced is a direct function of the orifice area. A rapid dump valve of, as yet, undetermined area has been proposed as part of the new, unified hatch on the CM. Within the boundaries imposed by other hatch-design constraints, the dump valve should be capable of being opened within several seconds and should be as large as possible without causing physiological boundary conditions to be exceeded.

The efficiency of the proposed system in extinguishing a fire in flight is predicated upon the creation of an atmosphere, in the minimum possible time, which will not support combustion. By rapidly starving the fire of oxygen, one minimizes temperature and pressure rise which would otherwise aid in propagating the fire. Preventing a temperature buildup also works against a reoccurrence of the fire and betters the chance of maintaining an atmosphere which is tolerable to crew members who, initially at least, are in constant-wear garments.

Thus, the immediate and concurrent actions required upon discovery of a fire in the spacecraft are (1) turn off cabin oxygen supply and circulating fans, (2) vent cabin through emergency dump valve and (3) activate purge of diluent gas. If the astronauts are in their suits, the procedures are simplified. The fire extinguishing system would be preset to maintain cabin pressure below the minimum suit loop operating pressure. This would minimize or eliminate the possibility of contaminating the suit loop with diluent gas. Hence, after allowing the system to operate for a given amount of time, the crew would close the dump valve, turn off the diluent gas system, and direct their attention to preventing a reoccurrence of the fire.

If the crew were in their constant-wear garments, they would require a supplemental emergency oxygen system for use during the fire extinguishing cycle. Since the fire extinguishing cycle is potentially less than a minute's duration, it also seems reasonable to require that the crew complete the cycle before donning their suits. The pressure suits and suit circuit have to be purged under these conditions to ensure that they are not contaminated by the diluent gas.

After the fire was extinguished and corrective action had been taken, the cabin atmosphere could be returned to normal by venting to a vacuum (with suits on) and then repressurizing with oxygen.

CONCLUSIONS AND RECOMMENDATIONS

This memorandum presents a scheme for dealing with spacecraft fires in flight. The effectiveness of using a diluent gas in tandem with cabin depressurization as a means of extinguishing or controlling a fire must be established. It is recognized that MSC has performed a number of tests which are similar to the method proposed herein. They have not, however, duplicated the time frame and the partial pressures of oxygen which the present study indicates are desirable. Therefore, it is recommended that experiments be performed to determine whether rapid reduction of oxygen partial pressure (i.e. 5-15 seconds) combined with maintaining a total pressure of 3 psia, by means of a diluent gas, is effective as a means of extinguishing a fire. If the results prove to be encouraging, it is further recommended that MSC initiate a design trade-off study aimed at selecting the best diluent gas and hardware system, with special attention given to the questions raised on gas dynamics and pressure effects.

With regard to the hardware aspects, it is suggested that those persons responsible for sizing the rapid dump valve in the new side crew hatch be made aware of these developments since the effective area of that valve is crucial to the attainment of a quick acting system.

The matter of timing must be stressed. From experience in all high performance jet aircraft, it has been found that emergency situations often degrade quite rapidly. Emergency systems in these vehicles require characteristics which contribute to an effective response by the crew members. That is, they should be <u>simple, reliable</u> and <u>accessible.</u> Further, they should be initiated through a basic, positive action on the part of a crew member. Crew training ties the emergency system together such that reactions in an emergency become almost automatic. Such factors must become part of any emergency system proposed for Apollo. Hardware design must also preclude inadvertent operation while allowing for restoration of normal conditions if inadvertent operation occurs.

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